Effect of Raw Material Source, Processing Systems, and Processing Temperatures on Amino Acid Digestibility of Meat and Bone Meals

X. WANG and C. M. PARSONS[1]

Department of Animal Sciences, University of Illinois, Urbana, Illinois 61801

ABSTRACT Experiments were conducted to evaluate amino acid digestibility of 32 commercial meat and bone meals (MBM) varying in raw material source and produced in seven different commercial cooking systems and at two processing temperatures (low vs high) that differed by 15 to 20 C. Raw material sources included all beef, all pork, mixed species, and high bone MBM. True digestibilities of amino acids were determined using the precision-fed cecectomized rooster assay. Protein efficiency ratio (PER) of six MBM varying greatly in amino acid digestibility was determined with chicks fed 10% CP diets containing a MBM as the sole source of dietary protein. The 32 MBM samples averaged 53.2% CP, 2.73% Lys, 0.6% Cys, and 0.75% Met on a DM basis. True digestibility averaged 82% for Lys, 87% for Met, and 47% for Cys. True digestibilities of amino acids varied substantially among processing systems and temperatures, particularly for Lys and Cys. For example, Lys and Cys digestibility ranged from 68 to 92% and from 20 to 71%, respectively, among different MBM. The higher processing temperature generally yielded lower amino acid digestibility than did the low processing temperature. A smaller, less consistent, effect was observed for raw material source. The PER values of the six selected MBM varied from 0.97 to 2.68 and were highly correlated with amino acid digestibility. These results indicated that very high amino acid digestibility MBM can be produced in commercial rendering systems. However, differences in processing systems and temperatures can cause substantial variability in amino acid digestibilities.

(*Key words*: meat and bone meal, amino acid digestibility, processing, poultry)

1998 Poultry Science 77:834–841

INTRODUCTION

Meat and bone meal (MBM) is an important feedstuff in poultry nutrition. This ingredient is a good source of protein, but the amino acid digestibility can very greatly. Sibbald (1986) reported that Lys and Cys digestibility of 21 MBM samples ranged from 45 to 86% and 30 to 64%, respectively. Parsons *et al.* (1997) reported that Lys and Cys digestibility of 14 MBM samples ranged from 69 to 91% and 37 to 88%, respectively. Raw materials (Skurray and Herbert, 1974) and processing conditions such as temperature and pressure are two factors that can affect protein quality of animal meals. Batterham *et al.* (1986) reported that Lys availability in MBM decreased from 86 to 31% as processing temperature increased from 125 C to 150 C. Johns *et al.* (1987) found negative effects of cooking time on amino acid digestibility of MBM heated at 150 C for 0, 1.5, 3, 4, and 5 h. In contrast, Herbert *et al.* (1974) reported that cooking time up to 2 h at 145 C had no detrimental effect on MBM protein quality. Most previous research on processing and MBM protein quality has been conducted using noncommercial or nonindustrial processing equipment or systems. Little research has been conducted to determine the reasons for the large variability in amino acid digestibility often observed in commercially rendered MBM. Therefore, the objectives of the present study were to further evaluate the variability in amino acid digestibility of commercial MBM and to evaluate effects of different raw material sources, industrial processing systems, and processing temperatures on amino acid digestibility of commercial MBM in attempt to identify the major factors responsible for the large variation in quality frequently observed for this ingredient.

MATERIALS AND METHODS

Meat and Bone Meals

Approximately 45.5 kg of 32 MBM (16 pairs) were obtained from commercial rendering plants that use

Received for publication August 7, 1997.
Accepted for publication January 12, 1998.
[1]To whom correspondence should be addressed: poultry@uiuc.edu

Abbreviation Key: MBM = meat and bone meal; NPR = net protein ratio; PER = protein efficiency ratio.

TABLE 1. Product description for meat and bone meals

Product[1]	Raw material source	Cooking system[2]	Processing temperature	Time in cooker/dryer[3]
			(C)	(min)
1 H	All beef	A	. . .	. . .
1 L				
2 H	All pork	A	152	105
2 L			132	105
3 H	Mixed species	A	152	75
3 L			132	60
4 H	High bone, low CP	A	149	60
4 L			132	60
6 H	All beef	B	140	15
6 L			110	20
7 H	All pork	B	140	15
7 L			110	20
8 H	Mixed species	B	140	15
8 L			110	20
10 H	All beef	C	141	50
10 L			129	50
11 H	All pork	C	149	60
11 L			135	60
12 H	Mixed species	C	132	70
12 L			113	80
17 H	All pork	D	110	45
17 L			96	45
18 H	Mixed species	E	141	180 to 240
18 L			113	180 to 240
21 H	High bone, low CP	F	141	180
21 L			121	180
28 H	All beef	E	125	240
28 L			110	240
29 H	All pork	E	125	240
29 L			110	240
31 H	Mixed species	G	113	180 to 240
31 L			102	180 to 240

[1]H = high processing temperature; L = low processing temperature.

[2]Cooking systems were (in random order): Atlas; Modified Low-Temperature; Batch; Dupps Continuous; Stord Continuous; Carver-Greenfield or Stord Slurry; and IBP-Coagulator.

[3]Estimated total residence time in the processing system. Includes time required for cooking and drying.

different processing systems, temperatures, and cooking and drying times. The descriptions of the raw material sources, processing systems, and processing temperatures for the MBM are presented in Table 1. The three types of raw material sources were all beef, all pork, and mixed species. The seven processing systems represented all of the major ones used in the rendering industry. These rendering systems included batch, continuous, continuous multi-stage evaporator, and continuous preheat/press/evaporator (Food and Drug Administration, 1996). The identity of the processing system for each product is not given for confidentiality. The processing of the products included both cooking and drying and the total residence or processing time varied greatly from 15 to 240 min among products. Each pair of products within processing system was prepared in the same processing plant at two different processing temperatures (high and low) on the same day in the attempt to ensure that raw material composition and processing conditions other than temperature of each pair of products would be similar. The difference between the low and high processing temperatures varied somewhat among systems and averaged 15 to 20 C.

The DM, CP, and ash contents of the 32 MBM were analyzed according to the procedures of the Association of Official Analytical Chemists (AOAC, 1980). Amino acids were analyzed by ion-exchange chromatography (Spackman *et al.*, 1958) following hydrolysis of samples in 6 *N* HCl for 24 h at 110 C. Analysis of Met and Cys were performed separately after performic acid oxidation using the procedure of Moore (1963), except that the excess performic acid was removed by lyophilization after dilution with water. Gross energy was determined using a bomb calorimeter.

Balance Assay for True Amino Acid Digestibility and TME_n

Cecectomized Single Comb Leghorn roosters were used in four 48-h assays. Cecectomy was performed according to the procedure of Parsons (1985) when the

TABLE 2. Dry matter, crude protein, ash, and gross energy in meat and bone meals[1]

Product	Dry matter	Crude protein	Ash	Gross energy
	(%)			(kcal/kg)
1 H	93.3	47.1	29.7	3,828
1 L	92.2	45.3	27.5	3,805
2 H	97.3	44.7	33.4	4,002
2 L	96.4	49.9	28.3	4,251
3 H	98.5	57.7	19.8	4,698
3 L	95.8	47.9	23.3	4,649
4 H	96.9	41.4	44.0	3,270
4 L	94.3	51.1	32.1	3,784
6 H	93.6	48.4	30.2	3,719
6 L	92.2	49.2	26.6	4,037
7 H	98.1	58.7	21.8	4,420
7 L	93.8	50.1	19.8	4,687
8 H	97.1	50.2	31.3	3,920
8 L	91.1	45.5	24.6	4,387
10 H	94.9	52.6	24.9	4,322
10 L	94.0	51.6	25.2	4,143
11 H	91.4	52.4	25.6	3,871
11 L	89.0	55.6	23.0	4,086
12 H	95.9	50.2	31.8	3,915
12 L	93.0	44.4	27.7	4,286
17 H	95.6	55.3	23.6	4,405
17 L	91.8	52.5	26.3	4,152
18 H	97.7	50.0	38.8	3,801
18 L	94.1	60.3	23.0	3,962
21 H	95.9	46.3	39.6	3,535
21 L	93.5	39.9	47.3	2,862
28 H	98.5	56.8	29.9	4,198
28 L	96.6	59.3	27.8	4,032
29 H	97.7	52.4	31.6	3,910
29 L	96.4	48.8	35.7	3,650
31 H	94.4	51.7	29.7	3,828
31 L	92.4	45.8	31.2	3,624
Mean	94.8	50.4	29.2	4,001

[1]Crude protein, ash, and gross energy values on an air-dry basis.

birds were 20 wk of age. The roosters were 32 wk old at the time of the first balance assay. The birds were housed in an environmentally controlled room and kept in individual cages with raised wire floors and subjected to 16 h light and 8 h dark daily. Feed and water were supplied for *ad libitum* access before the start of the experiment. Following a 24-h period without feed, one rooster was given 30 g of a MBM via crop intubation in each of four assays. The assays were repeated over time (4 wk between assays) because of the large number of samples to be evaluated. A plastic tray was placed under each cage and excreta were collected quantitatively for 48 h after crop intubation. Endogenous dry matter, N, and amino acid excretion were measured from roosters that were deprived of feed for 48 h. The excreta were freeze-dried, ground, and N, amino acids, and gross energy concentrations were determined according to the procedures described previously. True digestibilities of amino acids were calculated according to the method of Sibbald (1979), and TME_n by the method of Parsons *et al.* (1982).

Chick Assay for Protein Efficiency Ratio and Net Protein Ratio

Six MBM varying in amino acid digestibility were selected to determine protein efficiency ratio (PER) and net protein ratio (NPR). One-week-old female chicks from the cross of New Hampshire males × Columbian Plymouth Rock females were used. All chicks were housed in thermostatically controlled starter batteries with raised wire floors. Feed and water were supplied for *ad libitum* consumption, and light was provided 24 h daily. The chicks were fed a 23% CP corn-soybean meal pretest diet during the 1st wk posthatching. After an overnight period without feed, the chicks were weighed, wing-banded, and triplicate groups of six chicks were assigned to each dietary treatment as described by Sasse and Baker (1973).

Dietary treatments consisted of the N-free basal diet (Willis and Baker, 1980) or diets containing 10% CP provided by one of the MBM as the only source of protein. The MBM replaced some of the cornstarch and dextrose in the basal diet. The experimental diets were fed from 8 to 18 d of age. Body weight gain, PER (body weight gain / CP intake) and NPR [(body weight gain – body weight gain of chicks fed the N-free diet) / CP intake] were calculated for each MBM treatment.

Statistical Analysis

Completely randomized designs were used in both assays (Steel and Torrie, 1980). Data were initially

TABLE 3. Amino acid content of meat and bone meals[1]

Product	Thr	Cys	Val	Met	Ile	Leu	Tyr	Phe	Lys	His	Arg
						(%)					
1 H	1.40	0.42	1.72	0.54	1.11	2.89	0.90	1.57	2.21	0.73	3.44
1 L	1.31	0.48	1.66	0.54	1.06	2.72	0.86	1.51	2.16	0.67	3.26
2 H	1.25	0.33	1.57	0.65	1.07	2.54	0.84	1.45	2.17	0.70	3.22
2 L	1.38	0.40	1.91	0.70	1.23	2.91	1.01	1.63	2.58	0.85	3.45
3 H	1.77	0.57	2.42	0.87	1.46	3.98	1.33	2.12	2.92	1.16	3.69
3 L	1.75	0.53	2.08	0.76	1.26	3.46	1.17	1.83	2.76	1.19	3.25
4 H	1.05	0.35	1.50	0.48	0.84	2.08	0.62	1.19	1.57	0.54	2.71
4 L	1.80	0.87	2.28	0.62	1.44	3.34	1.06	1.90	2.24	0.90	3.60
6 H	1.60	0.50	1.77	0.69	1.23	2.96	1.01	1.57	2.28	0.82	3.33
6 L	1.63	0.67	1.93	0.68	1.28	3.06	1.04	1.66	2.54	0.91	3.36
7 H	1.85	0.66	2.22	0.85	1.52	3.50	1.25	1.94	3.11	1.08	4.15
7 L	1.61	0.61	1.96	0.73	1.33	3.14	1.13	1.74	2.87	0.96	3.65
8 H	1.59	0.69	1.85	0.67	1.24	3.14	1.04	1.73	2.68	0.88	3.93
8 L	1.63	0.67	2.05	0.69	1.40	3.21	1.08	1.81	2.38	0.92	3.69
10 H	1.81	0.74	2.27	0.78	1.54	3.61	1.23	1.93	2.98	0.93	4.21
10 L	1.74	0.84	2.28	0.71	1.52	3.48	1.13	1.89	2.94	0.89	3.97
11 H	1.78	1.16	2.25	0.74	1.50	3.43	1.21	1.83	2.28	0.88	4.57
11 L	1.84	0.97	2.15	0.74	1.44	3.46	1.25	1.81	2.82	0.94	4.46
12 H	1.64	0.50	2.47	0.79	1.49	3.35	1.10	1.88	2.99	1.01	3.83
12 L	1.51	0.48	2.28	0.82	1.40	3.11	1.02	1.76	2.88	0.99	3.15
17 H	1.76	0.85	2.18	0.78	1.42	3.19	1.12	1.70	2.66	0.88	4.11
17 L	1.66	1.05	2.01	0.72	1.32	3.04	1.05	1.65	2.59	0.84	3.91
18 H	1.50	0.59	1.98	0.67	1.01	2.18	0.98	1.61	2.38	0.94	3.30
18 L	1.80	0.70	2.16	0.82	1.52	3.39	1.16	1.85	2.76	1.08	3.42
21 H	1.34	0.46	1.78	0.66	1.13	2.58	0.84	1.48	2.16	0.77	3.37
21 L	0.99	0.32	1.37	0.48	0.82	1.86	0.53	1.12	1.67	0.51	3.04
28 H	1.82	0.62	2.14	0.85	1.63	3.56	1.18	1.93	2.97	1.07	3.88
28 L	1.99	0.74	2.34	1.02	1.77	3.90	1.20	2.07	3.23	1.25	3.97
29 H	1.45	0.45	1.82	0.77	1.33	2.87	0.89	1.60	2.53	0.84	3.57
29 L	1.40	0.41	1.82	0.74	1.31	2.78	0.73	1.57	2.47	0.82	3.61
31 H	1.65	0.65	2.17	0.59	1.50	3.01	0.90	1.68	2.65	0.88	3.47
31 L	1.55	0.56	2.00	0.55	1.38	2.77	0.83	1.53	2.42	0.78	3.30
Mean	1.59	0.62	2.01	0.71	1.33	3.08	1.02	1.70	2.57	0.89	3.62

[1]Air-dry basis. H = processed at high temperature, L = processed at low temperature.

subjected to ANOVA procedures using SAS® (SAS Institute, 1985). The TME_n and amino acid digestibility results were then analyzed as a 16×2 factorial treatment arrangement with 16 products and two processing temperatures. The digestibility values for Lys, Cys, Met, and Thr for Products 1 to 3, 6 to 8, 10 to 12, 18, 28, and 29 were further analyzed as a $3 \times 4 \times 2$ factorial treatment arrangement with three raw material sources (beef, pork, mixed species), four processing systems (A, B, C, E), and two processing temperatures (low, high). The least significant difference test (Steel and Torrie, 1980) was used to detect differences among treatment means in all analyses. Correlations between chemical composition (DM, CP, ash) and Lys and Cys digestibility values were assessed using Pearson's linear test (Steel and Torrie, 1980).

RESULTS

The DM, CP, ash, and gross energy content of the MBM averaged 95%, 50%, 29%, and 4,001 kcal/kg, respectively (Table 2), and varied among samples. For example, the CP ranged from 40 to 60%, and ash varied from 20 to 47%. The high bone MBM 4 and 21 had the highest ash and lowest CP and gross energy levels. The nutrient composition varied substantially between pairs of products processed at different temperatures in some cases, but there was no consistent relationship between processing temperature and nutrient composition. Amino acid content varied among the MBM (Table 3), with the average content of Lys, Met, and Cys being 2.6, 0.7, and 0.6%, respectively. Processing temperature had no consistent effect on amino acid content of the MBM.

TABLE 4. The TME_n content of the meat and bone meals[1,2]

Product	TME_n	TME_n/GE
	(kcal/kg)	
1 H	2,355	0.578
1 L	2,471	0.599
2 H	2,479	0.603
2 L	2,794	0.634
3 H	2,724	0.571
3 L	3,046	0.628
4 H	1,826	0.541
4 L	2,274	0.567
6 H	2,250	0.566
6 L	2,821	0.644
7 H	2,831	0.628
7 L	3,404	0.681
8 H	2,400	0.595
8 L	3,236	0.672
10 H	2,854	0.627
10 L	2,825	0.641
11 H	2,536	0.599
11 L	2,732	0.595
12 H	2,319	0.568
12 L	2,946	0.639
17 H	3,080	0.669
17 L	2,652	0.586
18 H	1,940	0.499
18 L	2,183	0.519
21 H	2,032	0.551
21 L	1,626	0.531
28 H	2,683	0.630
28 L	2,570	0.616
29 H	2,310	0.577
29 L	2,327	0.615
31 H	2,430	0.599
31 L	2,186	0.557
Mean	2,536	0.598
Pooled SEM	80	0.019
LSD[3]	223.8	0.053

[1]Values are on a dry matter basis.

[2]There was a significant ($P < 0.05$) effect of product and processing temperature on TME_n. The effect of product was also significant ($P < 0.05$) for TME_n/gross energy.

[3]Least significance difference or difference required between two means ($P < 0.05$).

The TME_n varied substantially among the MBM from 1,626 to 3,404 kcal/kg (Table 4). As expected, the TME_n of MBM 4 and 21 were low, probably due to their high ash and bone content. There was a significant ($P < 0.05$) effect of product and processing temperature on TME_n, with the low temperature yielding higher TME_n values for 11 of the 16 products. Similar responses were observed for TME_n/gross energy, although the differences were somewhat less than those observed for TME_n.

True amino acid digestibility varied substantially among MBM (Table 5); thus, the main effect of product was significant ($P < 0.05$) for all amino acids. The main effect of processing temperature was also significant ($P < 0.05$) for all amino acids, with the low temperature yielding higher amino acid digestibility values for most products. Although the magnitude of the temperature effect varied among products, the overall product by temperature interaction effect was not significant ($P > 0.05$). The results of the factorial analysis for 24 selected MBM and four amino acids are presented in Table 6. There was a significant ($P < 0.05$) interaction between processing system and raw material source for all four selected amino acids. The interaction occurred mainly because the amino acid digestibility of beef MBM was greater than that of pork MBM for Systems C and E, but the reverse occurred in Systems A and B. There was also a significant three-way interaction among variables for Met and Thr; however, this effect was difficult to explain and probably is not meaningful. Although there were some significant interactions among MBM parameters, the main effects of raw material source, processing system, and processing temperature are presented in Table 6 in attempt to more clearly illustrate the major effects of the three parameters on amino acid digestibility in the MBM. There was a significant ($P < 0.05$) effect of raw material type (beef, pork, mixed species) on digestibility of the four selected amino acids, and the results varied among amino acids. Generally, mixed species MBM had the lowest amino acid digestibility values, with digestibility for all four amino acids being lower ($P < 0.05$) than those for beef MBM. In addition, Met and Lys digestibility for mixed species MBM were lower ($P < 0.05$) than those for pork MBM, whereas there were no differences for Thr and Cys. Processing system and temperature also had a significant effect on amino acid digestibility. Processing Systems B and C generally produced higher amino acid digestibility values than Systems A and E. The low processing temperature yielded higher amino acid digestibility than the high processing temperature, with the effect being greatest for Cys.

Growth performance data and PER and NPR values from the protein quality chick assay are summarized in Table 7. As expected, chicks fed the N-free diet lost weight during the assay. Weight gain, PER and NPR varied greatly among the six MBM, with PER values ranging from 1 to 2.7. The mean PER for MBM 2H, 3H, and 4H (low amino acid digestibility) was 1.3 and the mean PER of MBM 7L, 8L, and 10L (high amino acid digestibility) was 2.4. The NPR values for the high amino acid digestibility MBM were also much higher ($P < 0.05$) than those for the low amino acid digestibility MBM.

Correlation analyses for DM, CP and ash content vs Cys and Lys digestibility and TME_n indicated that the only significant correlations were for ash content (Table 8). Ash content was highly correlated with TME_n (r = –0.83). Significant negative correlations were also found for ash and digestible TSAA, Cys, and Lys per unit of CP. Correlations between ash and amino acid digestibility coefficients were generally 0.4 or less and not significant ($P > 0.05$).

DISCUSSION

In general, the average CP and amino acids for the MBM agreed with the NRC (1994), although values varied greatly among samples. The values for the low and high temperature meals within products also varied substantially in some cases even though they were processed in the same plant on the same day in an attempt to minimize variation in composition between the samples. The latter variation could be explained largely by differences in ash content in most cases. The differences in ash content were likely due to differences in bone content in the original raw materials or due to separation during grinding of the processed samples in the rendering plants. Many of the plants had considerable difficulty grinding the 45.4-kg sample that was used

TABLE 5. True digestibility of amino acids in meat and bone meals[1,2]

Product	Thr	Cys	Val	Met	Ile	Leu	Tyr	Phe	Lys	His	Arg
	(%)										
1 H	76.4	30.9	87.1	83.6	89.2	88.6	60.3	82.2	76.7	80.7	88.1
1 L	75.6	35.5	87.2	85.3	88.4	88.4	55.7	81.3	82.3	76.6	87.1
2 H	71.6	20.5	85.2	86.7	87.2	87.1	52.3	78.8	77.6	73.0	85.8
2 L	78.7	38.7	89.5	88.4	90.8	90.3	65.8	84.2	85.2	84.5	86.9
3 H	73.7	31.2	83.5	82.8	83.0	84.4	72.1	80.1	71.1	74.0	86.3
3 L	82.6	50.2	89.5	89.7	90.4	90.6	73.3	85.4	81.2	81.9	89.6
4 H	68.4	22.8	81.9	78.4	82.3	81.2	46.4	72.9	71.3	72.1	74.7
4 L	81.7	54.6	89.6	83.2	91.3	89.9	74.9	86.1	82.1	84.5	85.6
6 H	83.2	46.5	90.7	89.8	92.4	92.2	67.7	86.0	85.9	85.5	89.6
6 L	87.0	65.1	93.3	90.9	94.0	93.7	74.6	89.0	86.0	87.3	90.6
7 H	87.0	61.9	92.8	90.9	93.4	93.9	75.1	91.8	90.5	88.4	92.9
7 L	89.0	70.7	94.2	91.2	94.6	95.2	75.4	93.3	91.9	90.5	93.4
8 H	79.4	51.2	85.0	86.4	86.0	88.5	63.0	84.8	86.7	88.0	86.9
8 L	86.7	59.2	91.7	90.9	92.8	93.2	73.5	90.4	90.8	90.2	88.5
10 H	83.8	56.7	92.1	90.8	93.3	92.6	71.4	88.4	89.3	88.6	92.0
10 L	87.5	70.8	94.4	91.9	95.3	94.5	78.1	91.1	89.7	88.5	92.6
11 H	72.7	44.1	84.3	87.9	87.6	86.0	66.2	82.6	80.7	80.1	83.3
11 L	77.1	47.6	87.9	88.0	90.9	90.7	71.8	86.4	85.5	82.2	89.3
12 H	78.9	37.1	90.5	88.0	91.3	89.4	67.3	84.6	83.7	83.7	85.3
12 L	82.5	48.6	92.6	91.1	93.3	91.6	71.3	87.0	86.9	85.3	88.1
17 H	76.0	52.3	87.3	88.8	89.9	88.2	67.6	84.2	83.5	78.5	85.3
17 L	71.9	36.8	84.2	85.4	86.6	85.5	59.5	80.6	82.4	78.9	84.4
18 H	60.1	38.6	74.8	75.8	67.2	64.2	45.0	67.4	68.8	72.1	76.0
18 L	70.7	42.1	80.8	82.0	83.2	81.8	60.8	76.2	67.9	70.0	73.1
21 H	75.9	34.7	86.3	84.4	86.9	86.5	62.9	80.8	81.2	83.8	83.3
21 L	74.7	43.7	86.0	83.7	86.3	84.7	54.4	77.9	77.4	78.8	78.9
28 H	78.1	45.9	86.7	87.1	89.8	88.2	70.7	83.5	78.7	78.5	84.2
28 L	84.3	58.3	91.2	91.6	93.1	92.2	72.8	88.1	87.3	83.9	90.2
29 H	73.7	33.4	83.8	85.5	87.7	85.2	62.0	79.7	74.9	74.6	80.8
29 L	76.5	48.3	86.3	88.1	89.9	87.5	50.4	80.3	81.7	82.3	80.6
31 H	84.7	59.8	90.7	85.0	91.6	90.1	71.7	88.4	85.4	86.7	84.4
31 L	82.8	65.2	89.1	81.3	90.4	88.9	64.9	86.4	85.5	84.7	85.7
Mean	78.5	47.0	87.8	86.7	89.1	88.3	65.6	83.7	82.2	81.8	86.0
SEM	2.22	5.93	1.52	1.32	1.60	1.49	4.11	1.79	2.38	2.19	1.78
LSD[3]	6.3	16.8	4.3	3.7	4.5	4.2	11.6	5.1	6.7	6.2	5.0

[1]Values are means of four cecectomized roosters. H = processed at high temperature, L = processed at low temperature.

[2]Main effects of product and processing temperature were significant ($P < 0.05$) for all amino acids.

[3]Least significant difference or difference required for significance between two means ($P < 0.05$).

TABLE 6. Effect of raw material source, processing system, and processing type on digestibility of selected amino acids in meat and bone meals

Parameter	Lys	Cys	Met	Thr
	(%)			
Raw material source[1]				
Beef (1, 6, 10, 28)	84[a]	51[a]	89[a]	82[a]
Pork (2, 7, 11, 29)	84[a]	46[a]	88[a]	78[b]
Mixed species (3, 8, 12, 18)	80[b]	45[a]	86[b]	77[b]
SEM	0.9	2.1	0.4	0.7
Processing system[1]				
A (1–3)	79[b]	34[c]	86[b]	76[c]
B (6–8)	89[a]	59[a]	90[a]	85[a]
C (10–12)	86[a]	51[b]	90[a]	80[b]
E (18, 28, 29)	77[b]	44[b]	85[b]	74[d]
SEM	1.0	2.4	0.5	0.8
Processing temperature				
Low temperature	84[a]	53[a]	89[a]	81[a]
High temperature	81[b]	42[b]	87[b]	77[b]
SEM	0.6	1.7	0.4	0.7
	Probabilities			
ANOVA results				
Raw Material Source (RMS)	0.001	0.071	0.001	0.001
Processing System (PS)	0.001	0.001	0.001	0.001
Temperature (T)	0.001	0.001	0.001	0.001
PS × RMS	1.001	0.003	0.001	0.001
PS × T	0.641	0.832	0.189	0.056
RMS × T	0.193	0.820	0.699	0.643
PS × RMS × T	0.082	0.424	0.001	0.001

[a–c]Means within a column and subgrouping with no common superscript differ significantly ($P < 0.05$).

[1]Values in parentheses are the product numbers.

in our research. There was no relationship between processing temperature and ash content (mean ash for high temperature = 30%; mean ash for low temperature = 28%) or processing temperature and CP content (mean CP for high temperature = 51%; mean CP for low temperature = 50%), indicating that the ash and CP variation occurred randomly and was not associated with processing temperature.

Although raw material source influenced amino acid digestibility, there is no apparent explanation for the response. The overall effect was primarily due to the lower amino acid digestibility of mixed species MBM vs

TABLE 7. Determination of protein quality of meat and bone meals varying in amino acid digestibility[1]

Treatment	Amino acid digestibility	Weight gain	Gain: feed	PER[2]	NPR[2]
		(g)	(g:g)		
1. Basal (N-free)[3]		–5.6[e]	–0.053[3]	. . .	. . .
2. As 1 + 2H[4]	low	19.3[c]	0.152[c]	1.52[c]	1.96[c]
3. AS 1 + 3H	low	17.6[c]	0.132[c]	1.32[c]	1.73[d]
4. As 1 + 4H	low	10.7[d]	.098[d]	0.97[d]	1.49[e]
5. As 1 + 7L	high	40.1[a]	0.269[a]	2.68[a]	3.05[a]
6. As 1 + 8L	high	33.4[b]	0.238[b]	2.37[b]	2.77[b]
7. As 1 + 10L	high	33.1[b]	0.225[b]	2.26[b]	2.64[b]
SEM		1.3	0.007	0.08	0.08

[a–e]Means within a column with no common superscript differ significantly ($P < 0.05$).

[1]Means of three replicates of six chicks each. Average initial weight was 75.0 g.

[2]PER = protein efficiency ratio = weight gain (grams) divided by protein intake (grams); NPR = [weight gain (grams) of birds fed test diet minus weight gain of birds fed the N-free diet] divided by protein intake (grams).

[3]Composition (percentage): cornstarch:dextrose (2:1), 89.23; soybean oil, 5; glista salts, 5.37; choline chloride, 0.20; vitamin premix, 0.20; α-tocopheryl acetate, 20 ppm; and ethoxyquin, 125 ppm (Willis and Baker, 1980).

[4]Product number and high (H) or low (L) processing temperature. All products were added to the N-free basal diet to furnish 10% CP.

TABLE 8. Significant ($P < 0.05$) correlation coefficients for ash content vs TME_n and amino acid digestibility for meat and bone meals

Correlation	r
Ash vs TME_n	–0.83
Ash vs digestible TSAA per unit CP	–0.54
Ash vs digestible Cys per unit CP	–0.50
Ash vs digestible Lys per unit CP	–0.53

beef or pork MBM. Thus, it seems that the amino acid digestibility of mixed species MBM may be slightly lower than all beef or all pork MBM in some cases.

Our results indicated that type of commercial processing system may substantially affect the amino acid digestibility of MBM. Part of the processing system response could be associated with processing temperature. For example, the processing temperatures for System A were higher than those for System B. The differences in processing temperature do not explain the lower amino acid digestibility values for System E vs B, as processing temperatures were similar for both. However, the combined cooking and drying time for System E was much longer than for Systems B and C and may be at least partially responsible for the differences in amino acid digestibility. Most of the MBM produced in System B had Met and Lys digestibility coefficients of 90% or greater. These results indicated that very high quality MBM can be produced in commercial rendering systems.

The finding that processing temperature influenced amino acid digestibility is in agreement with the studies by Skurray and Herbert (1974), Batterham *et al.* (1986) and Johns *et al.* (1987). Our results further indicate that the effect of processing temperature may vary among processing systems. For example, the effect of processing temperature was generally greater in Systems A and E than in B. As discussed above, part of this differential response may be due to processing temperature within system or length of cooking time. The finding that the effect of processing temperature was greatest for Cys was unexpected. It is generally assumed that the effects of temperature or overprocessing would be greatest for the basic amino acids, especially Lys, due to formation of Maillard reaction products (Hurrell and Carpenter, 1981). The latter has been shown for several oilseed meals (Parsons *et al.*, 1992; Anderson-Hafermann *et al.*, 1993; Zhang and Parsons, 1994). That the effect of temperature on Lys digestibility in MBM was less pronounced that temperature effects in oilseed meals may be due to low carbohydrate and reducing sugar content of MBM. The reason for the large effect of processing temperature on Cys digestibility unknown. Perhaps some of the effect is due to formation of lanthionine or lysinoalanine (Robbins *et al.*, 1980). The dramatic effect of processing temperature on Cys digestibility is particularly important as Cys or sulfur amino acid is the first limiting amino acid in MBM for chicks (Wang *et al.*, 1997).

The PER and NPR measurements are good estimates of basic protein quality in feed ingredients. These assays have been used extensively in animal and human nutrition for decades. The results of the chick assay confirmed that selected MBM having low amino acid digestibility did, indeed, have lower PER and NPR values than MBM having high amino acid digestibility. The differences in PER and NPR values were probably primarily due to differences in the amount of digestible sulfur amino acid or Trp per unit of CP in the MBM, as these are the two first limiting amino acids in MBM for chicks (Wang *et al.*, 1997). For example, the mean digestible sulfur amino acid/CP values for the three low digestibility MBM was 1.36% compared to 2.29% for the three high digestibility MBM.

As discussed earlier for amino acids, high processing temperature also had a negative effect on TME_n of the MBM. This reduction was not due to differences in gross energy, because TME_n/gross energy values were also decreased at the high processing temperature. Part of the negative effect of high processing temperature was likely due to deceased amino acid digestibility.

The significant negative correlation of MBM ash content with digestible sulfur amino acid/CP content agrees with the finding of Parsons *et al.* (1997). This effect and the similar one for Lys is likely due to the increase in bone and collagen content in association with increased ash. Eastoe and Long (1960) have shown that collagen protein is very low in most essential amino acids. The low correlation between ash and amino acid digestibility coefficients (r values generally 0.4 or less) observed herein agrees with the earlier work by Johnson (1996) and Parsons *et al.* (1997). In those studies, there was no significant relationship between ash and amino acid digestibility coefficients although high ash meals had lower concentrations of several essential amino acids per unit of CP. Thus, the negative effect of ash on protein quality of MBM as measured by PER and NPR is primarily due to reduced concentrations of important essential amino acids, not reduced digestibility of amino acids.

REFERENCES

Anderson-Hafermann, J. C., Y. Zhang, and C. M. Parsons, 1993. Effects of processing on the nutritional quality of canola meal. Poultry Sci. 72:326–333.

Association of Official Analytical Chemists, 1980. Official Methods of Analysis. 13th ed. Association of Official Analytical Chemists, Washington, DC.

Batterham, E. S., R. F. Lowe, R. E. Darnell, and E. J. Major, 1986. Availability of lysine in meat meal, meat and bone meal and blood meal as determined by the slope-ratio assay with growing pigs, rats and chicks and by chemical techniques. Br. J. Nutr. 55:427–440.

Eastoe, J. E., and J. E. Long, 1960. The amino acid composition of processed bones and meat. J. Sci. Food Agric. 11:87–92.

Food and Drug Administration, 1996. Docket 96 N-0135. Substances prohibited from use in animal food or feed; protein derived from ruminants prohibited in ruminant feed. Section 5. Rendering or processing practices in the United States, FDA, Rockville, MD.

Herbert, L. S., J. F. Dillon, M. W. MacDonald, and G. B. Skurray, 1974. Batch dry rendering: influence of processing condition on meat meal quality. J. Sci. Food Agric. 25: 1063–1070.

Hurrell, R. F., and K. J. Carpenter, 1981. The estimation of a available lysine in feedstuffs after Maillard reactions. Prog. Food Nutr. Sci. 5:159–176.

Johns, D. C., C. K. Low, J. R. Sedcole, M. P. Gurnsey, and K.A.C. James, 1987. Comparison of several in vivo digestibility procedures to determine lysine digestibility in poultry diets containing heat treated meat and bone meals. Br. Poult. Sci. 28:397–406.

Johnson, M. L., 1996. Evaluation of ash content and processing temperature on protein quality of meat and bone meal, poultry by-product meal and lamb meal in poultry and ileal-cannulated dogs. M. S. Thesis, University of Illinois, Urbana, IL.

Moore, S., 1963. On the determination of cystine as cysteic acid. J. Biol. Chem. 238:235.

National Research Council, 1994. Nutrient Requirements of Poultry. 9th rev. ed. National Academy Press, Washington, DC.

Parsons, C. M., 1985. Influence of cecectomy on digestibility of amino acids by roosters fed distillers dried grains with solubles. J. Agric. Sci. Camb. 104:469–472.

Parsons, C. M., F. Castanon, and Y. Han, 1997. Protein and amino acid quality of meat and bone meal. Poultry Sci. 76: 361–368.

Parsons, C. M., and K. Hashimoto, K. J. Wedekind, Y. Han, and D. H. Baker, 1992. Effect of overprocessing on availability of amino acids and energy in soybean meal. Poultry Sci. 71:133–140.

Parsons, C. M., L. M. Potter, and B. A. Bliss, 1982. True metabolizable energy corrected to nitrogen equilibrium. Poultry Sci. 61:2241–2246.

Robbins, K. R., D. H. Baker, and J. W. Finley, 1980. Studies on the utilization of lysinoalanine and lanthionine. J. Nutr. 110:907–915.

SAS Institute, 1985. SAS® Users Guide: Statistics. Version 5 Edition. SAS Institute Inc., Cary, NC.

Sasse, C. E., and D. H. Baker, 1973. Availability of sulfur amino acids in corn and corn gluten meal for growing chicks. J. Anim. Sci. 37:1351–1355.

Sibbald, I. R., 1986. The T.M.E. system of feed evaluation: methodology, feed composition data and bibliography. Contribution 85-19. Agriculture Canada. Ottawa, ON, Canada.

Sibbald, I. R., 1979. A bioassay for available amino acids and true metabolizable energy in feedstuffs. Poultry Sci. 58: 668–673.

Skurray, G. B., and L. S. Herbert, 1974. Batch dry rendering; influence of raw materials and processing condition on meat meal quality. J. Sci. Food Agric. 25:1071–1079.

Spackman, D. H., W. H. Stein, and S. Moore, 1958. Automatic recording apparatus for use in the chromatography of amino acids. Anal. Chem. 30:1190–1206.

Steel, R.G.D., and J. H. Torrie, 1980. Principles and Procedures of Statistics. A Biometrical Approach. 2nd ed. McGraw-Hill Book Co., Inc., New York, NY.

Wang, X., F. Castanon, and C. M. Parsons, 1997. Order of amino acid limitation in meat and bone meals. Poultry Sci. 76:54–58.

Willis, G. M., and D. H. Baker, 1980. Evaluation of turfgrass clippings as a dietary ingredient for the growing chick. Poultry Sci. 59:404–411.

Zhang, Y., and C. M. Parsons, 1994. Effects of overprocessing on the nutritional quality of sunflower meal. Poultry Sci. 73:436–442.